Classroom Radio Telescope

Mario Capitolo
Science Department
Bellarmine College Preparatory
San Jose, California 95126-1899
marioc@bcp.org

William Lonc
Astronomy and Physics Dept.
Saint Mary's University
Halifax, N.S., Canada, B3H 3C3
william.lonc@stmarys.ca

Your very own radio telescope, small enough to fit in a corner of a classroom or lab can be built for $300 to $400 plus a few hours of time.

What can this radio telescope do? At the very least, the system can do the following:

1. Detect microwaves emitted by the Sun; most of the microwave flux will be a combination of thermal (blackbody) and nonthermal processes.

2. Detect microwaves emitted by the human body; this is blackbody radiation associated with a source of about 360 K (273 + body temperature).

3. Detect microwaves emitted by any other object of sufficiently high temperature.

4. On the basis of the above, this system provides several experiments at the high-school or college level involving the concept of blackbody radiation. It is readily admitted that the experiments are 'simple-minded', in the sense that many factors are simply being ignored. The justification for neglecting these factors is that they are of second-order magnitude. From another point of view, one could hope that the students would raise questions pertaining to perturbing effects as the experiment was being conducted.

This particular telescope was assembled at Bellarmine College Prep. High School in San Jose, California, and makes use of readily available Ku-band (12 GHz) satellite TV equipment in which the dish is fed off-center. The diameter of the dish is just over 24" and therefore can be easily moved through a typical classroom door for observations outside. This type of dish has the advantage of being more sensitive than the older on-axis feeds because the center of the dish is not obstructed by whatever happens to be at the dish's focal point (usually an LNB--Low-Noise Block converter).

Question: What's an LNB? The LNB shifts the spectrum of the incoming electromagnetic radiation from a 500-MHz wide 'slice' centered at about 12 GHz (this is in the microwave part of the spectrum) to a similar 'slice' centered at about 1300 MHz (this is in the UHF part of the spectrum). In the typical domestic application, the satellite-TV receiver (this is not the TV set) selects one of the many channels appearing in this 'slice', and converts the selected channel to a lower frequency (usually VHF channel #3 or #4) to be viewed on the TV set.

In our case, the LNB was on a line 23 deg below the dish-axis, meaning that the antenna was actually 'looking' along a line 23 deg above the dish-axis. To minimize confusion when pointing the telescope at a specific object, a protractor was installed (see Figure 7) at the apex of the dish. For a typical classroom situation, the dish needs to be mounted on a pedestal different from the one normally supplied. We used a sturdy tripod mounted on casters, as shown in the photo at the end of the article. A shelf was fitted to the tripod behind the dish to support the chart-recorder and a power-bar. The voltage-offset module was fastened to the tripod. The entire system ws therefore easy to move around the lab as well as to school-yard.

The 'off-the-shelf' units used in this project are associated with 'analog' type of satellite TV. Since, at the time of writing (January,1996), digital satellite TV systems are rapidly gaining popularity, it should be possible to acquire a trade-in analog system for a relatively low price. Our system, consisting of the dish and LNB (with appropriate feed-horn) was a used Channel Master and cost us $330.

A block-diagram of our system (system #1) is shown in Figure 1.

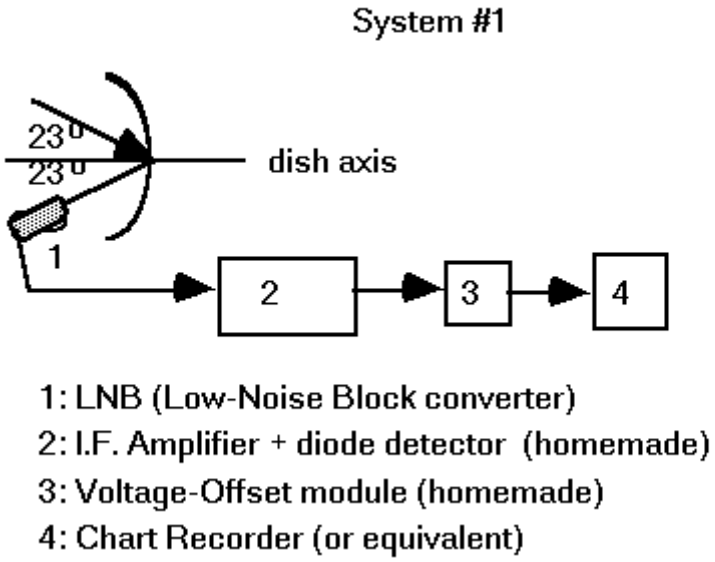


Figure 1: Block diagram of the system as actually used for this report. The dish and LNB (with associated supports) were commercial units. The homemade I.F. amplifier and diode detector had a bandwidth of over 500 MHz (the circuit is given at the end of this article).

Evidently, the chart-recorder could be replaced by a DVM (digital voltmeter) or computer-controlled data-acquisition system.

A block diagram of a substitute system, with somewhat less sensitivity than system #1, is shown in Figure 2.

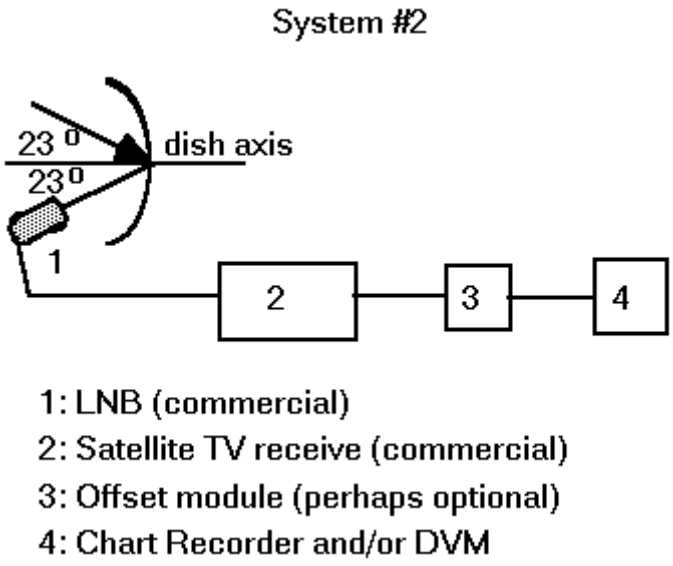
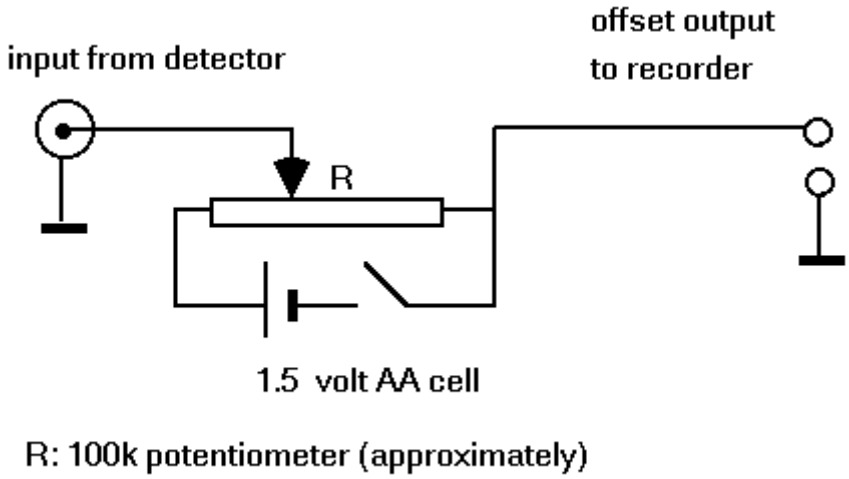


Figure 2: Block diagram of a system that is somewhat less sensitive than the above, but quite capable of producing all the results described in this article. Here, rather than a home-made wide-band I.F. amplifier, a commercial receiver (matching the LNB) is used, in which the effective bandwidth associated with the tuning meter is around 25 MHz.

As mentioned above, a DVM or computer-controlled data-acquisition system could serve as the telescope output device.

Figure 3: Figure 3: Schematic diagram of an 'voltage-offset module'. In this case, the a battery polarity will offset positive voltage appearing between the coax input connector and ground. To offset a negative voltage, simply reverse the battery.



The output connectors were 5-way binding posts, spaced at 0.75" for compatibility with standard banana-type connectors. It may be advisable to connect a capacitor at the input to the chart-recorder to suppress noise superimposed on the d.c. signal, especially if the recorder is operating at high sensitivity (e.g., 5 mV/inch).

The major difference, from the point of view of hardware, between systems #1 and #2 is the use of an 'off-the-shelf' satellite TV receiver in system #2 rather than a home-made amplifier+detector. For those opting to use system #2, the signal (a d.c. voltage in the order of tens of millivolts when looking at the Sun) is taken from across the tuning meter of the satellite TV receiver. Most manufacturers have included a connection at the back of the receiver to which a DVM or other suitable d.c. meter is connected when positioning the antenna for correct orientation at the time of installation. Hence, a user could opt to simply connect a DVM at this connector, dispensing with the 'voltage-offset module' as well as the recorder. Needless to say, the recorder (or something equivalent) is desirable because it provides the user(s) with a hard copy of the data.

Let's take a look at some experiments (even Science Fair projects) that are possible with this system. The list is not in any particular order. Comments are added to provide somewhat detailed information on how to go about doing the experiment. In these experiments, it is rather important to ensure that no contaminating microwave radiation (e.g., from fluorescent lights) is entering the feed-horn. Remember, anything warmer than absolute zero emits microwaves!

1. Equivalent blackbody temperature of the quiet Sun at 2.5 cm wavelength (approximately 12,000 K).

2. Demonstration that the human body emits microwaves.

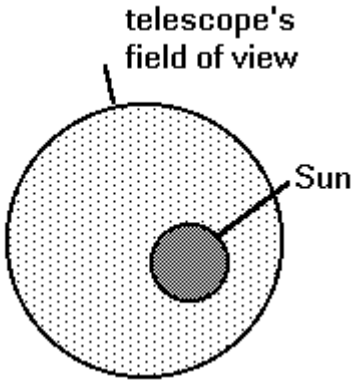
3. Demonstrate that the temperature of an object is related to the emission of microwaves from that object; e.g., from liquid nitrogen to boiling water.

4. Demonstrate that the clear sky has a temperature fairly close (within a factor of two or so) to the Big Bang microwave background temperature.

Experiment #1: The theory of the experiment is based on the assumption that the telescope's field of view is larger than the angular size of the Sun, and that the ratio of these two angular areas (solid angles), as shown in Figure 4, tells us by how much to multiply the temperature obtained from the calibration curve to obtain the equivalent blackbody temperature of the Sun. See Reference 2 for more details on this procedure. Cloud-cover will have no noticeable effect on these experiments.

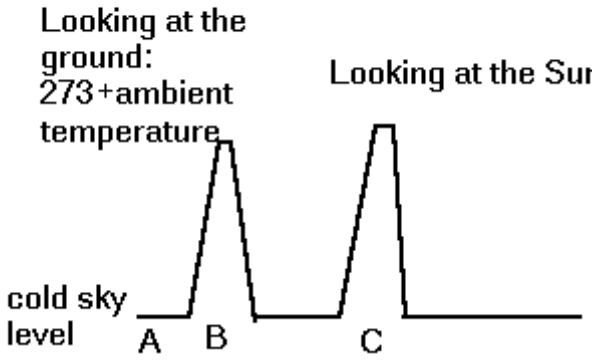
Figure 4: Angular area is taken to be proportional to (D/2)^2, where D is the angular diameter. For the Sun, D = 0.5 deg. arc; for the telescope, D = 3 deg arc. The ratio of the angular areas is approximately 36. Hence, if the telescope voltage output corresponds to a temperature of

340 K (on the basis of the cali-bration curve), then the equivalent blackbody temperature of the Sun at 12 GHz is 340 × 36 = 12,200 K.



The experiment involves a measurement of the half-power beam-width of the telescope (i.e., the 'field of view' at the half-power points) using an approximately point source (i.e., the Sun) and the calibration of the telescope at approximately 6 K and 300 K to obtain a calibration curve. The Sun is approximately a point source because its angular diameter (0.5 deg arc) is much less than the typical beamwidth of the antenna (about 3 deg arc). For this experiment, it is necessary to somehow measure angular displacement in the equatorial plane (assuming that the rotation axis of the antenna is vertical).

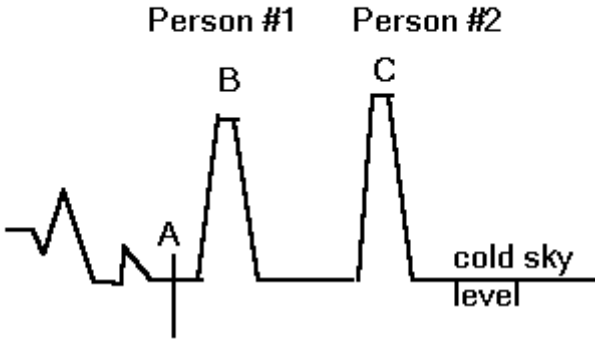
Figure 5: Idealized chart-recording showing the initial maneuvers to calibrate the telescope at the cold-sky temperature, indicated by A. The telescope is pointed in various directions until the minimum output is obtained; this is the first calibration point. The temperature is nominally 6 K. The telescope is then pointed at the ground to obtain another calibration point, B. Finally, at C, the telescope is pointed at the Sun.



Experiment #2: This is a fairly simple experiment, in which the telescope is pointed towards a relatively cold part of the sky and then people are invited to step in front of the telescope. There will be a very noticeable deflection; since the receiver responds only to microwaves. For the skeptics, a black plastic garbage bag can be placed in front of the feed horn to verify that it is not visible electromagnetic radiation that is causing the output device to indicate presence of microwaves). Since the typical human body does not, probably, fill the telescope ffield of view, then it is not really all that possible to determine the equivalent blackbody temperature of the human body involved. However, the fact that the output device does move upscale indicates that microwaves are being emitted. Students have been observed to vie with each other to see who is the 'hottest' or 'coolest' in the group.

Figure 6: Idealized chart recording for Experiment #2. At first, the telescope is adjusted so that it is looking about 20 degrees above the horizon at an empty sky (no trees, satellites, etc. allowed), and then back and forth along azimuth (about 10 degrees or so) until it is looking at the coldest part of the sky; this produces a minimum deflection of the pen, marked A on the chart. Then a person climbs up on a short ladder and stands in front of the dish in such a way as to fill as much of the telescope beamwidth as possible. Stand about a meter or so away from the LNB. The deflection is marked B for this

particular person. The deflection for another person is marked C, etc.



Experiment #3: To show that the microwave intensity is associated with the temperature of an object, the idea is to place an object of variable temperature at a suitable point in front of the telescope and then monitor the output as a function of temperature. For simplicity, the object must subtend a constant angular size relative to the antenna. It turns out that a glass beaker (1L) placed just in front of the feed horn (i.e., right at the LNB) is satisfactory because it fills much (if not all) of the feed horn's aperture. A styrofoam beaker or bottle would be even more satisfactory.

A suitable platform is needed to hold the beaker just in front of the horn. A preliminary exercise could be to have the antenna pointing in some arbitrary direction in the classroom and then to place an empty beaker on the holder and verify that the beaker is not affecting the behavior of the apparatus.

Actually, if only this particular experiment is needed. then it is not necessary to have the dish antenna. Simply place the LNB (with its feed horn) on a suitable stand and proceed from there. As mentioned above, it is necessary to keep in mind that the interior of the classroom is at about 300 K and therefore filling the classroom with microwaves. If there are fluorescent lights in the room, then the ambient microwave radiation is even more intense.

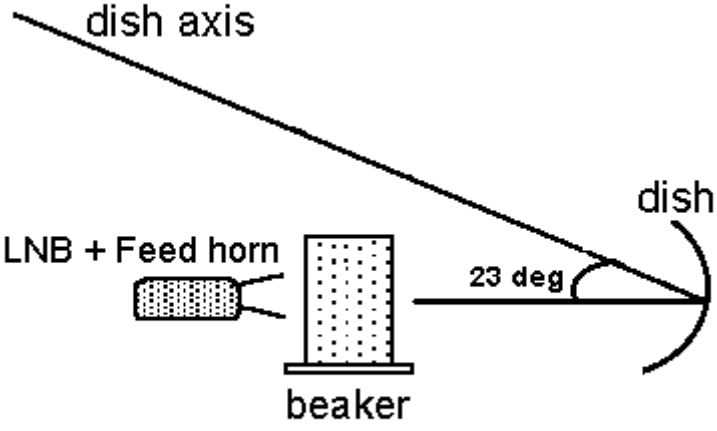
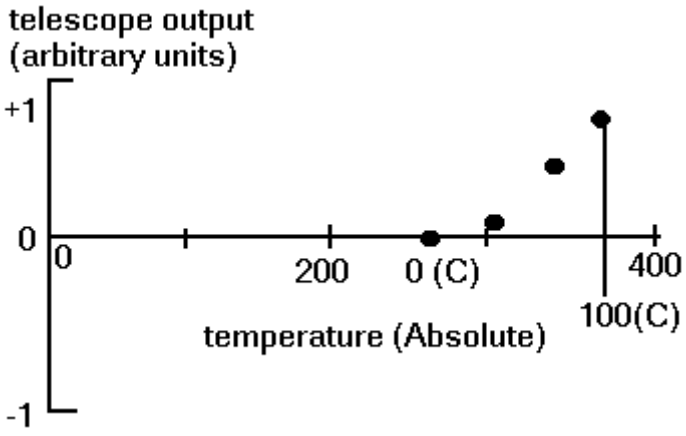


Figure 7: A block diagram of the experimental arrange-ment to measure the microwave emission from some object (e.g., water) at various temperatures. A suitable beaker holder needs to be fitted more or less as shown. In our experiment, we simply filled the beaker with water at several different temperatures and measured the telescope (we could also call it a microwave radiometer) output each time. It is rather important to ensure that no contaminating microwave radiation (e.g., from fluorescent lights) is entering the feed-horn.

Figure 8: An idealized graph obtained using the procedure described above. The voltage-offset module was used to set the output voltage of the system (input voltage at the chart recorder or equivalent) to zero volts when the substance was at 0o C. Note that the data does not follow a straight line, perhaps contrary to expectation. The basic reason is that the blackbody radiation depends on the fourth power of the blackbody temperature.

Also, the LNB itself produces microwaves consistent with an object at a temperature specified by the 'Noise Temperature' of the LNB (given by the manufacturer; usually about 50 K for typical off-the-shelf units). For the purposes of the experiment, however, it suffices to find that the temperature of the substance and its associated blackbody microwave emission are related in a fairly simple manner.



References

1. John D. Kraus, Radio Astronomy, 2nd ed., Cygnus Quasar Book, P.O. Box 85, Powell, OH, 43065. The book is also available from Radio-Sky Publishing, P.O. Box 3552, Louisville, KY., 40201; email radiosky@radiosky.win.net.

2. George Lo and William Lonc, "Solar Temperature at 4GHz: An undergraduate experiment," Am.J.Phys., 54, 843-6 (1986). Additional discussions of concepts and projects suitable for senior high-school will be found in the book Radio Astronomy Projects, (by W. Lonc) available from Radio-Sky Publishing for $20 plus $3 shipping.

Figure 9: Parts Values

C1: 10 uF
C2: 0.1 uF
C3: 0.001 uF
C4: 4.7 pF

L: 6 uH
R1: 470, 1/8 watt
R2: 100, 1/4 watt

Note that C3 is a feed-through capacitor.

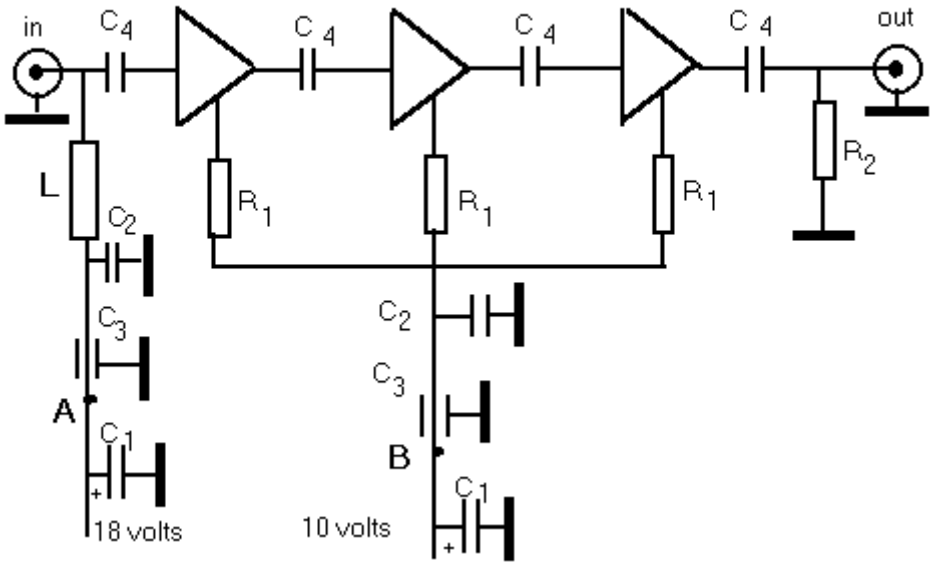


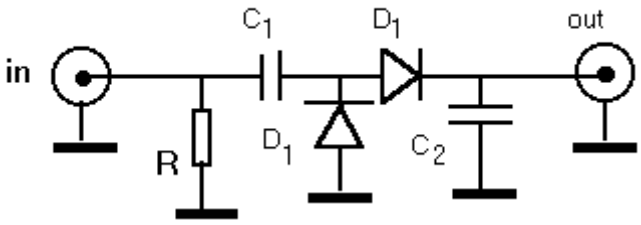
Figure 9: Schematic diagram of the home-built wide-band I.F. amplifier. This circuit requires some previous experience in constructing ultra high frequency circuits.

The home-built I.F. amplifier module has three micro-monolithic integrated circuits (MMIC's), and the circuit is shown in Figure 9. Using these MMIC's greatly simplifies construction of a wide-band amplifier. The input and output impedance of both the converter and home-built I.F. module is a nominal 50 ohms. Note that the I.F. amplifier supplies the power (18 volts at approximately 0.1 amperes) to the converter and does this by sending this d.c. power along the coax cable between the converter and the I.F. amplifier module. This is an example of 'multiplexing'. The I.F. amplifier module needs about 10 volts at some 25 mA. In our experiment, we simply used a resistor of about 250 ohms between points A and B in Figure 9 and fed 18 volts to the module as shown.

Figure 10: Schematic diagram of the home-built

detector module.

Parts List:
C1: 4.7 pF
C2: 0.01 uF
D1: 1N34 or equivalent.
R: 100 ohm, non-inductive.



Our detector presented a suitable load to the output of the home-built I.F. amplifier. Since the detector is operating in the UHF part of the spectrum, appropriate care is needed in its construction. For the beginner, it is suggested that a person experienced in UHF techniques be consulted. Note that the I.F. amplifier and detector can be built in the same box, thereby simplifying the combined circuit. As shown, the detector provides a postive-going d.c. output; if a negative-going output is desired, then simply reverse both diodes.

The completed Classroom Radio Telescope

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